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A CATHODE RAY TUBE DISPLAY

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A CATHODE RAY TUBE DISPLAY

Jack Stifle

ABSTRACT

This report describes a cathode ray tube display unit designed for use as a graphic output facility for a digital computer.

The display features a self contained character generator, line generator, photographic unit, and a light pen. Data may be displayed in up to seven different modes.

The maximum plotting rate is approximately 333,000 points/sec.

ACKNOWLEDGMENT

The successful completion of this project involved the talents of several people.

Thanks are due to Brian Voth who designed the camera unit and to Leonard Hedges who supervised the layout and construction of the display and assisted in the system debugging.

Thanks also are due to George Crawford, Jim Knoke, Tony Susedik, Fred Holy, Mike Johnson, Leo Streff and Paul Tucker all of whom assisted in the actual construction, and to Virginia Metze who wrote the programs used to check out the system.

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CHAPTER 1 - TECHNICAL SUMMARY

1-Q INTRODUCTION

This report describes a computer driven display system designed for displaying a wide variety of computer generated data. Design attention has been focused on making the system flexible, easy to program and operate, and requiring a minimum of computer memory space.

1-1 SPECIFICATIONS

Display Medium

Electrostatically deflected 17 inch CRT.

Word Length

24 bits - 12 bits for X; 12 bits for Y; 4096 positions along each axis.

Operating Modes

Seven modes of operation available; may be expanded to 16.

Self contained character and line generators.

Operating Speeds

333,000 points/sec

50,000 characters/sec

16,600 lines/sec

Camera Unit

Magnetically deflected 5 inch CRT with Polaroid camera. Camera may be program operated.

Input-Output

IBM typewriter

Light Pen

CHAPTER 2 - OPERATING MODES

2-0 GENERAL

The data to be displayed consists of 24 bit Display Words stored in a Display List which occupies a portion of the computer memory. In the CDC 1604 computer, two Display Words are stored in each memory location. See Fig. 2-0.

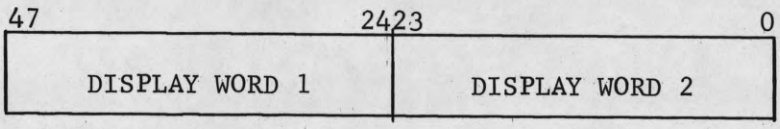


Fig. 2-0 Display Data (1604)

The 1604 transmits a 48 bit word to the Display each output cycle, where it is disassembled into the two Display Words for processing.

Display Words may be of two types; control words and/or data words. The data words contain the data to be displayed while the control words specify to the Display the mode of displaying the data. The ability of the Display to process data in different modes greatly reduces the memory space required in the computer and allows easy processing of a variety of data.

To simplify program control of the Display List, a "Looping Buffer" modification was added to the 1604. The program establishes a Looping Buffer by executing a 74 0 04140 instruction. This instruction causes the buffer containing the Display list to automatically recycle after the last word in the buffer has been transmitted to the Display. (The buffer is transmitted to the Display on Channel 6 in the 1604.) Once activated, the Looping Buffer no longer requires any supervision by the program. Any portion of the memory may be used as a Looping Buffer. The program may read and write information in the Display List at any time and even expand the buffer, if required.

To terminate the Looping Buffer, the computer executes a 74 0 04141 instruction. Execution of this instruction will cause the buffer to terminate the next time the last word has been transmitted.

2-1 MODE CONTROL WORD (MCW)

The Display may be operated in any of several modes as directed by the computer. For each mode there is an associated Mode Control Word (MCW). The MCW directs the Display processing of incoming computer data. The Display remains in a given mode until directed by the computer to change modes.

The MCW format is shown in Fig. 2-1.

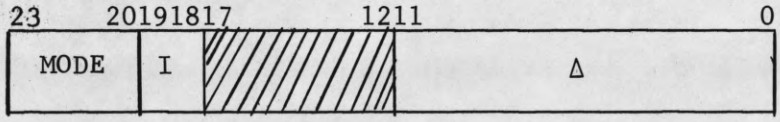


Fig. 2-1 MCW Format

Bits 20-23 specify the Display mode

Bits 18-19 specify the intensity for this mode. Four intensity levels are available, ranging from 00 (minimum) to 11 (maximum)

Bits 12-17 are unused

Bits 00-11 specify, when appropriate, an increment which modifies either or both coordinates (x and/or y).

2-2 CONTROL SWITCH WORD (CSW)

The Control Switch Word (CSW) prepares the display for receipt of a MCW. The CSW is a display word containing "1" in all bit positions.

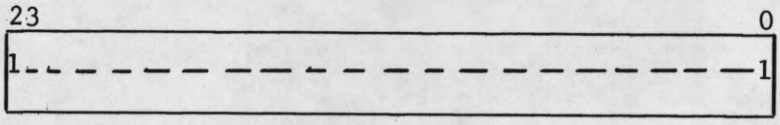


Fig. 2-2 CSW Format

The first word following the CSW will be interpreted by the Display as the MCW. If several CSW words are sent in sequence, the first non-CSW word will be treated as the MCW. A CSW must always precede a MCW to prevent erroneous operation. The display remains in a given mode of operation until receipt of a CSW.

Note that the format of the CSW precludes the use of a data word (in all modes) containing all "1's".

2-3 MODE 01

Mode 01 is a point plotting mode.

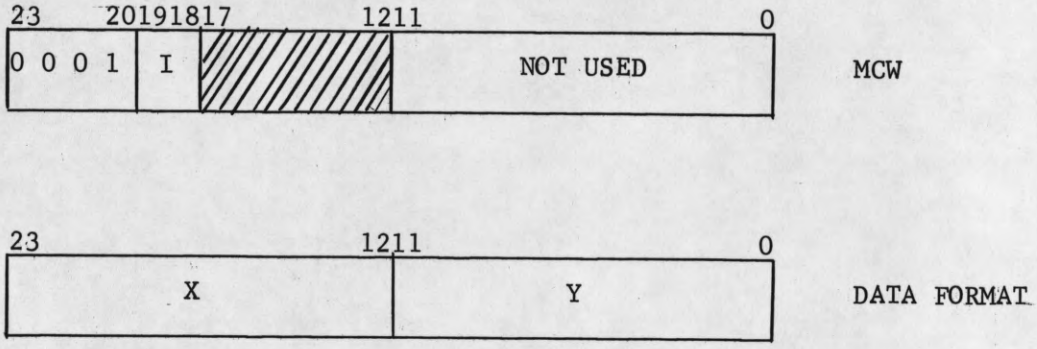


Fig. 2-3 Mode 01 Format

Each data word following the MCW specifies a point location. Bits 0-11 specify the Y and bits 12-23 the X coordinate of the point.

All points will be displayed at intensity level I of the MCW. Bits 0-11 of the MCW are not used in Mode 01. The plotting rate in Mode 01 is approximately 333,000 points/sec.

2-4 MODE 02

Mode 02 is a graph or incremental plotting mode using X as the independent variable.

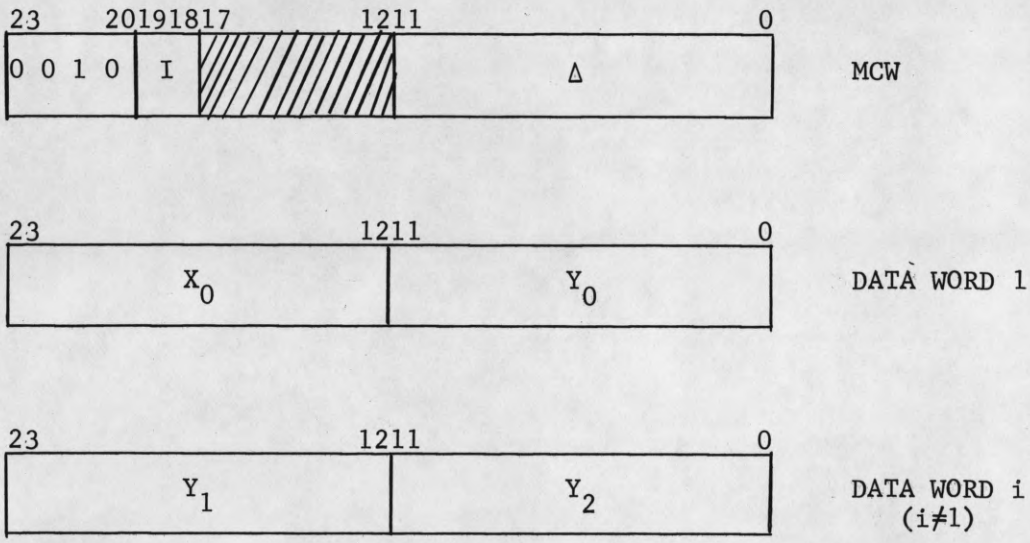


Fig. 2-4 Mode 02 Format

The first data word following the MCW specifies the origin point while all succeeding data words contain two successive Y coordinates. For each successive Y coordinate the X coordinate will automatically be incremented by Δ of the MCW. The graph will be plotted at intensity level I of the MCW. The plotting rate in Mode 02 is approximately 333,000 points/sec.

2-5 MODE 03

Mode 03 is a graph or incremental plotting mode using Y as the independent variable.

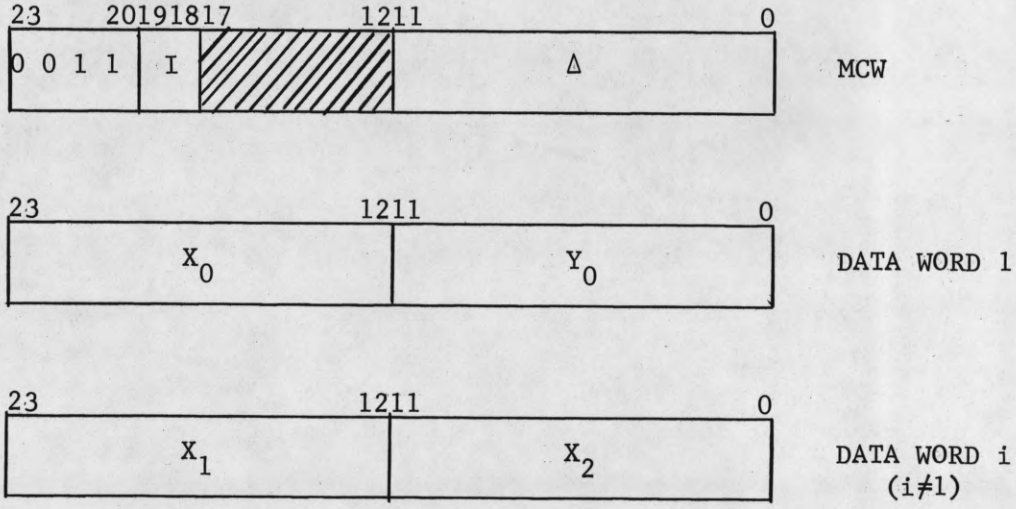


Fig. 2-5 Mode 03 Format

The first data word following the MCW specifies the origin point while all succeeding data words contain two successive X coordinates. For each successive X coordinate the Y coordinate will be automatically incremented by Δ of the MCW.

The graph will be plotted at intensity level I of the MCW.

The plotting rate in Mode 03 is approximately 333,000 points/sec.

2-6 MODE 04

Mode 04 is a matrix mode which may be used to construct special symbols.

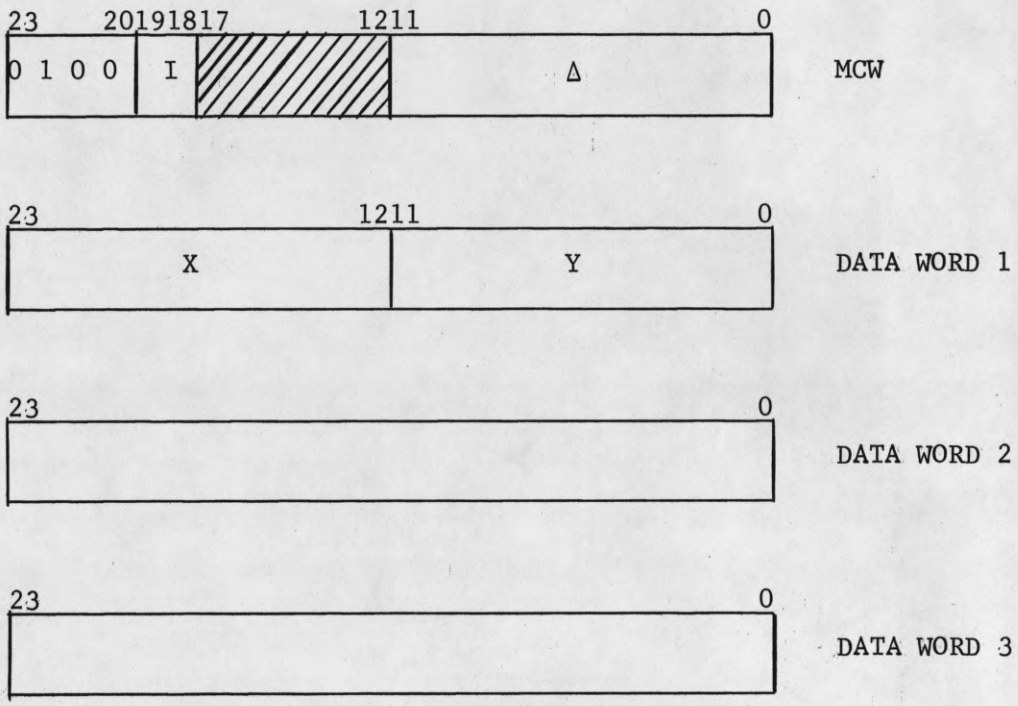


Fig. 2-6 Mode 04 Format

The first data word on each group of three data words following the MCW specifies the origin of an 8 X 6 matrix. The remaining pair of data words in each group specify which positions in the matrix are to be displayed.

Each position in the matrix corresponds to a bit position in one of the two data words. A point in the matrix will be displayed if its corresponding bit position is a "1".

The symbol matrix is shown in Fig. 2-7. Data word 1 locates the beam at the upper left corner (bit 23 of data word 2) of the matrix. After the matrix has been plotted the beam is left resting at the lower left corner (bit 00 of data word 3) of the matrix.

Adjoining matrices may be generated by appropriate choice of the first data word in each group of three data words. This permits large matrices which can be used to generate complex symbols.

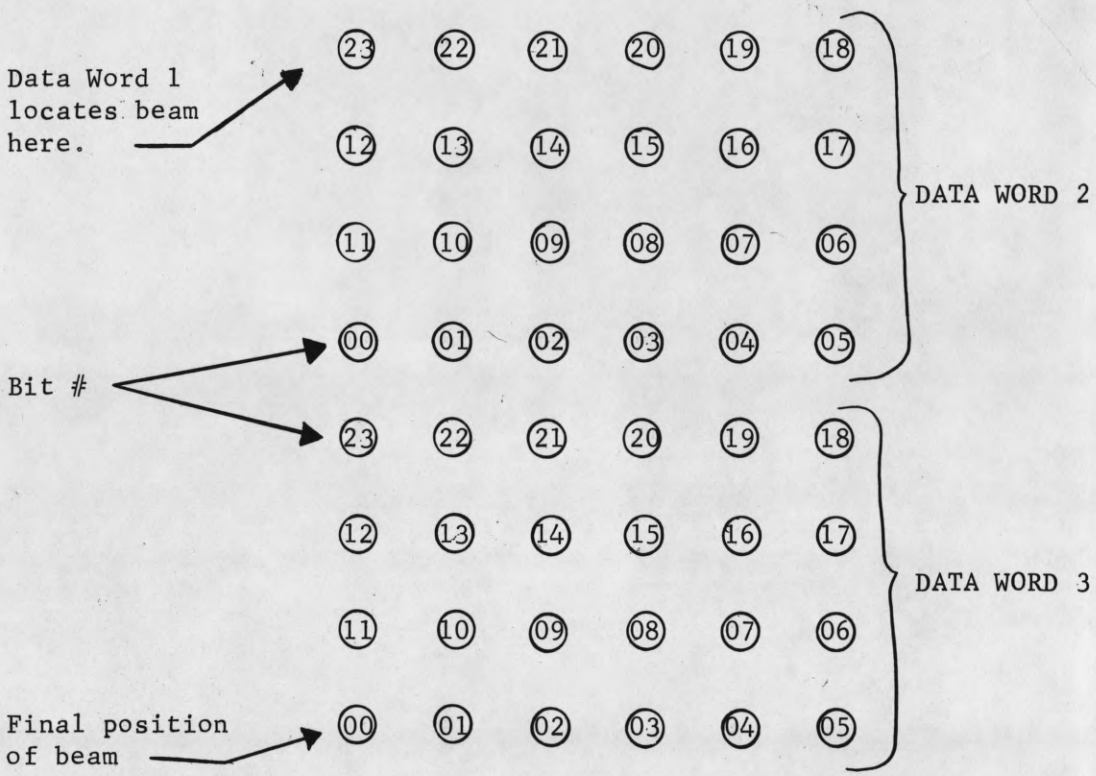


Fig. 2-7 Symbol Matrix

The horizontal and vertical spacing in the matrix is specified by Δ of the MCW. The matrix will be displayed at intensity level I of the MCW.

The plotting time per matrix is approximately 1.5 μs multiplied by the number of points to be displayed.

2-7 MODE 05

Mode 05 is a line segment mode.

Each pair of data words following the MCW specify the coordinates for the origin and terminal points, respectively of a line.

All lines will be drawn at intensity level I of the MCW. Bits 00-11 of the MCW are not used in this mode.

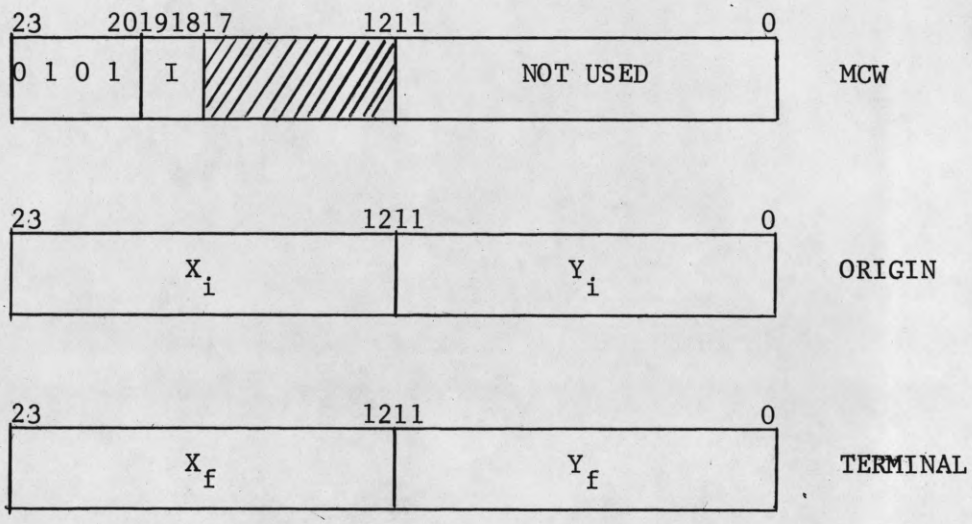


Fig. 2-8 Mode 05 Format

The line plotting time is approximately 60 μs/line regardless of line length.

2-8 MODE 06

Mode 06 is a continuous line generating mode.

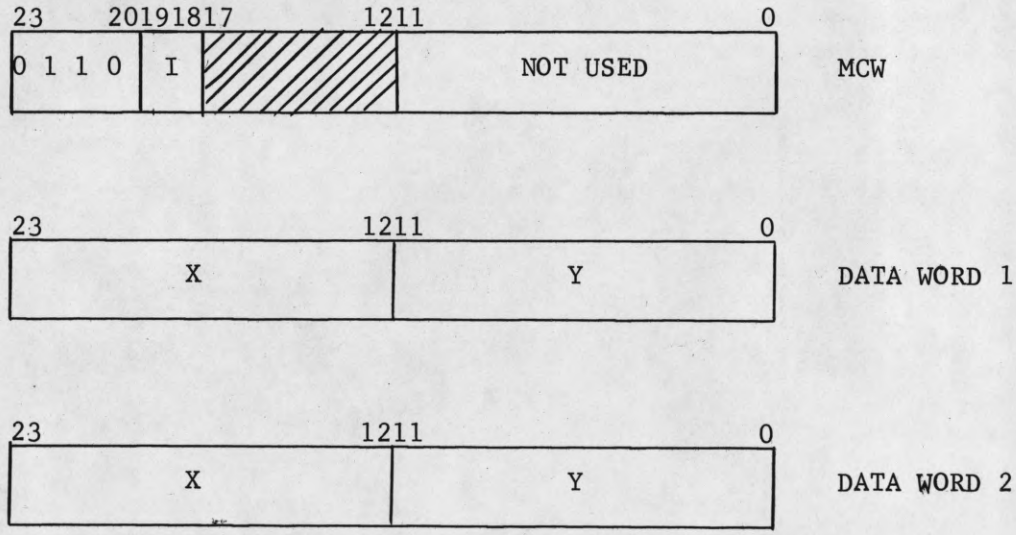


Fig. 2-9 Mode 06 Format

Data word 1 specifies the origin of a line. Each succeeding word specifies the end point of the preceding line which also is interpreted as the origin point of the next line.

All lines will be drawn at intensity level I of the MCW. Bits 00-11 of the MCW are not used in this mode.

The line plotting time is approximately 60 μs/line regardless of line length.

2-9 MODE 07

Mode 07 is a character typing mode.

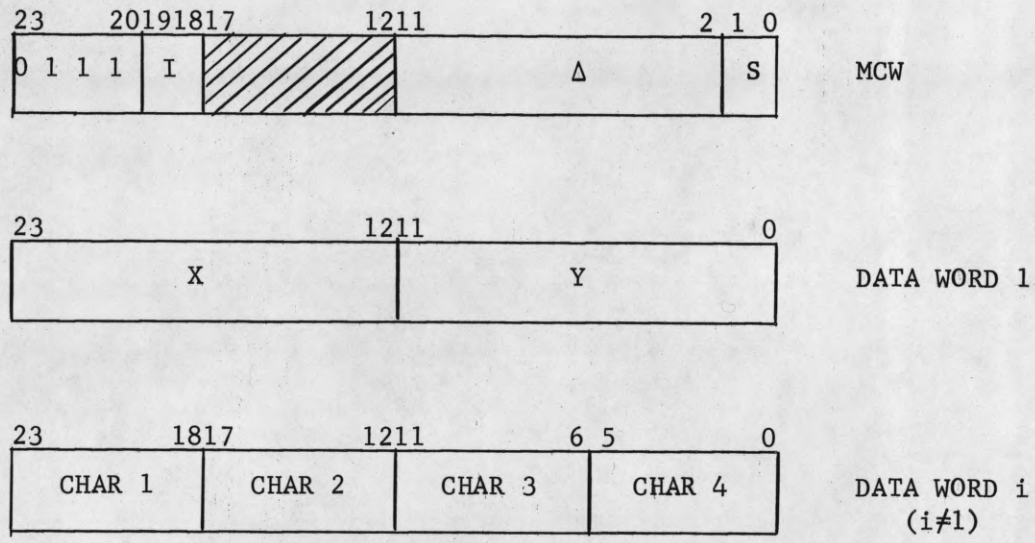


Fig. 2-10 Mode 07 Format

The first data word following the MCW specifies the origin of the first character or line of characters. Each succeeding data word contains the BCD codes for four characters.

The list of character codes is shown in Fig. 2-11.

CHARACTER	BCD
A	61
B	62
C	63
D	64
E	65
F	66
G	67
H	70
I	71
J	41
K	42
L	43
M	44
N	45
O	46
P	47
Q	50
R	51
S	22
T	23
U	24
V	25
W	26
X	27
Y	30
Z	31
Ø	12
1	01
2	02
3	03
4	04
5	05

CHARACTER	BCD
6	06
7	07
8	10
9	11
?	76
:	00
,	33
.	73
|	16
;	77
_	40
=	13
+	60
/	21
[	34
]	74
≠	14
≡	36
≤	15
≥	75
<	72
>	57
→	35
←	37
↑	55
↓	56
÷	17
*	54
SPACE	20
CARRIAGE RETURN	32
Δ	52
$	53

Fig. 2-11 Character Codes

Four character sizes are available and are specified by bits 00-01 of the MCW.

Size Code	
00	133 characters/line (with $\Delta = 100_8$)
01	96 characters/line (with $\Delta = 125_8$)
10	64 characters/line (with $\Delta = 202_8$)
11	32 characters/line (with $\Delta = 403_8$)

Bits 02-11 of the MCW specify character line spacing. Character spacing will be 1/2 of the line spacing. All characters will be plotted at intensity level I of the MCW.

Character plotting rate is approximately 50,000 char/sec. (20 μs/char).

2-10 MODE 00

Mode 00 is a control mode used to control the operation of the camera unit.

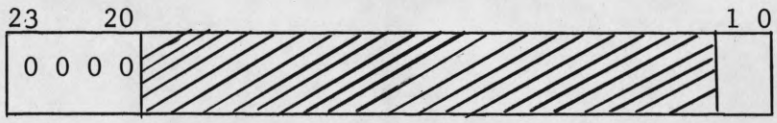


Fig. 2-12 Mode 00 Format

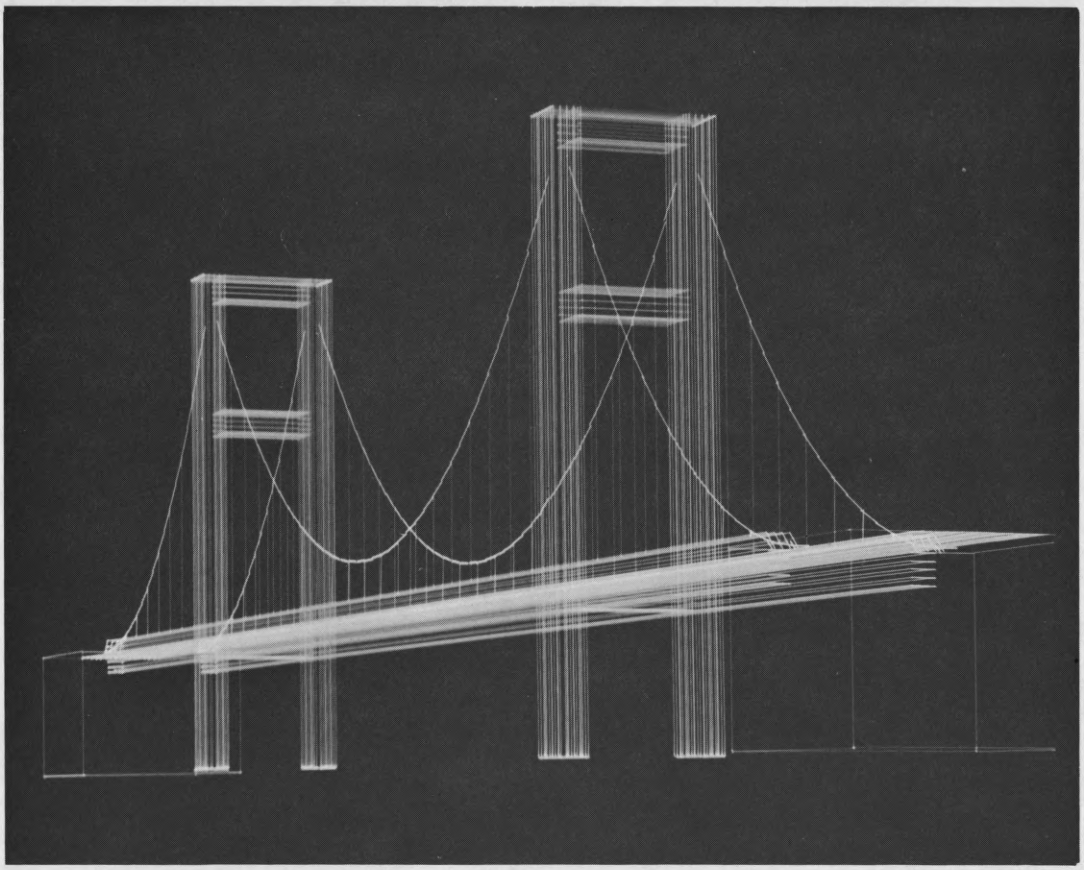
BIT	
0	1 = Select Photographic Mode
	0 = Clear Photographic Mode
1	1 = Open camera shutter
	0 = Close camera shutter

Selecting the photographic mode activates the 5 inch CRT in the camera unit and at the same time reduces the display rate.

Operation of the camera shutter is asynchronous with the flow of display data. The transfer of data to the display is temporarily halted by the display until the camera shutter has been opened or closed.

Since there are no data words associated with Mode 00, a new mode selection must be made following a Mode 00 control operation.

The pictures on the following pages are actual unretouched photographs taken by the camera unit. They are typical examples of the type of data that may be displayed.



THIS IS AN UNRETOUCHED PHOTOGRAPH TAKEN BY THE CAMERA UNIT WHICH ILLUSTRATES THE CHARACTER FORMAT. THESE CHARACTERS WERE GENERATED USING DISPLAY MODE 07.

CHARACTERS MAY BE DISPLAYED IN FOUR SIZES AND FOUR INTENSITY LEVELS.

LARGE ABCDEFGHIJKLMNOP
QRSTUVWXYZ1234567890+=!-
⟋.,▲+✝>≥≠≡:?÷$✝✝<≤;!

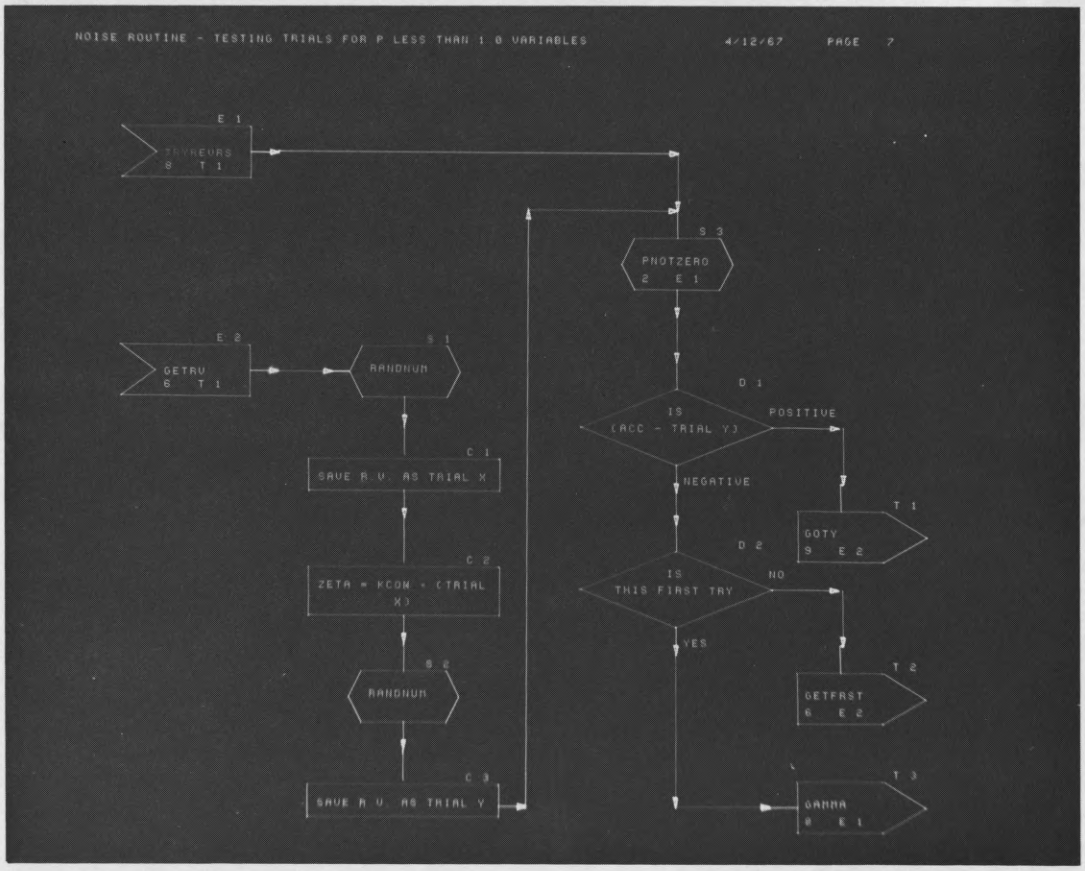
MEDIUM ABCDEFGHIJKLMNOPQRSTUVWXYZ1234567890+=!-/.,
▲+✝>≥≠≡:?÷$✝✝<≤;!

SMALL ABCDEFGHIJKLMNOPQRSTUVWXYZ1234567890+=!-/.,▲+✝>≥≠≡:?÷$✝✝<≤;!

EXTRA SMALL ABCDEFGHIJKLMNOPQRSTUVWXYZ1234567890+=!-/.,▲+✝>≥≠≡:?÷$✝✝<≤;!

CHARACTERS MAY ALSO BE DISPLAYED VIA DISPLAY MODE 04. THE FOLLOWING ARE EXAMPLES OF SUCH CHARACTERS

abcdefghijklmnopqrstuvwxyz 0123456789 =+'-!/.,
ABCDEFGHIJKLMNOPQRSTUVWXYZ)*@#$%¢&½(+*" ¡?.,



CHAPTER 3 - SYSTEM DESCRIPTION

3-0 GENERAL

The Display, Fig. 3-0, is composed of eight functional units. These are:

1) An Interface unit which controls the exchange of information between the display and a computer.
2) A Processer unit which performs all arithmetic and logical operations on the display data.
3) An Analog unit which converts data from digital to analog form for display.
4) A Line Generator.
5) A Character Generator.
6) A CRT unit which provides a visual display.
7) A Camera unit for photographic recording of data.
8) An Input-Output section for operator control.

3-1 INTERFACE UNIT

The two primary functions of the Interface unit are 1) the conversion of signal levels between computer and display, and 2) the assembly of computer words into display words. This latter function is necessary since the display is a 24 bit word device while the computer with which it is operating may have a different word length.

The Interface unit is the only portion of the display that is computer dependent. Therefore, to operate the display with a different computer, it is necessary only to replace the Interface unit. (For the remainder of this report it will be assumed that the display is operating with a CDC 1604 computer.)

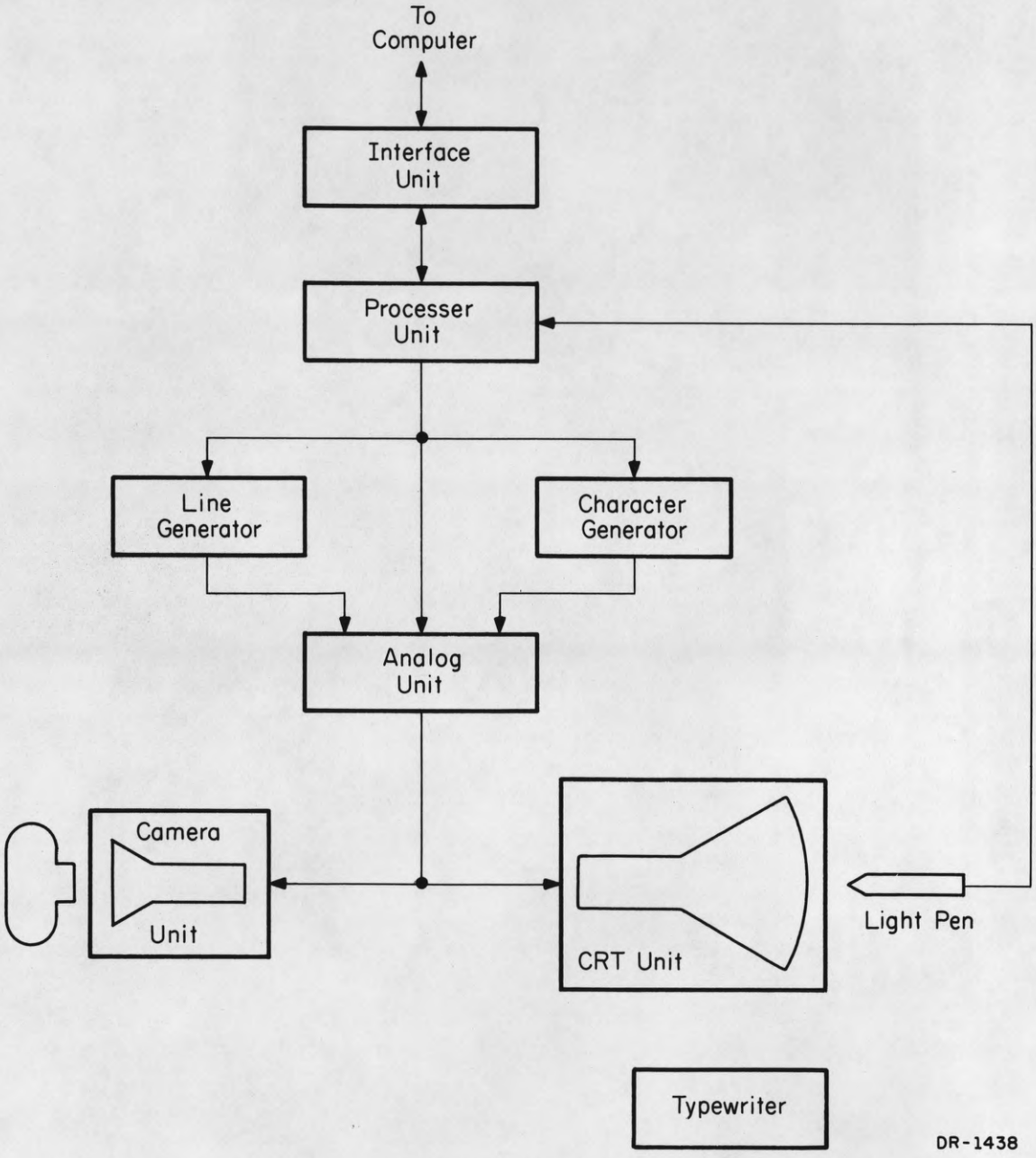


Fig. 3-0 DISPLAY BLOCK DIAGRAM

The Interface unit, Fig. 3-1, contains a 48 bit register (I) and a control section.

The I register holds a 48 bit computer word while it is disassembled into two 24 bit display words for transmission to the Processer unit. The control section provides the gating signals for controlling the flow of data through the I register and the control signals for communicating with the computer.

3-2 PROCESSER UNIT

The Processer unit, Fig. 3-2, receives the incoming digital data from the Interface unit and performs all necessary computations on the data while it is being displayed.

All data entering the Processer unit from the Interface unit enters via the 24 bit D register. The upper 12 bits of D(D^U) or the lower 12 bits (D^L) may be transferred to any of the registers in the display except Z.

The X and Y registers are the principal registers in the display. The contents of these 12 bit registers specify the base position (coordinates) of the electron beam. The output of each register is sent to the Analog unit where the digital to analog conversion is performed. The output of each register is also available to the A_1 input to the Adder.

The 12 bit Δ register holds the quantity Δ of the MCW. This quantity is generally used to modify the contents of either or both the X and Y registers.

Three outputs from this register are available to the A_2 input of the Adder. These are 1) the actual contents, 2) $\frac{1}{2}$ the actual contents, and 3) the one's complement of the contents. The actual contents are used to increment another quantity by Δ; the $\frac{1}{2}$ output is used to increment a quantity by $\frac{1}{2}\ \Delta$; while the one's complement is used to decrease a quantity by Δ.

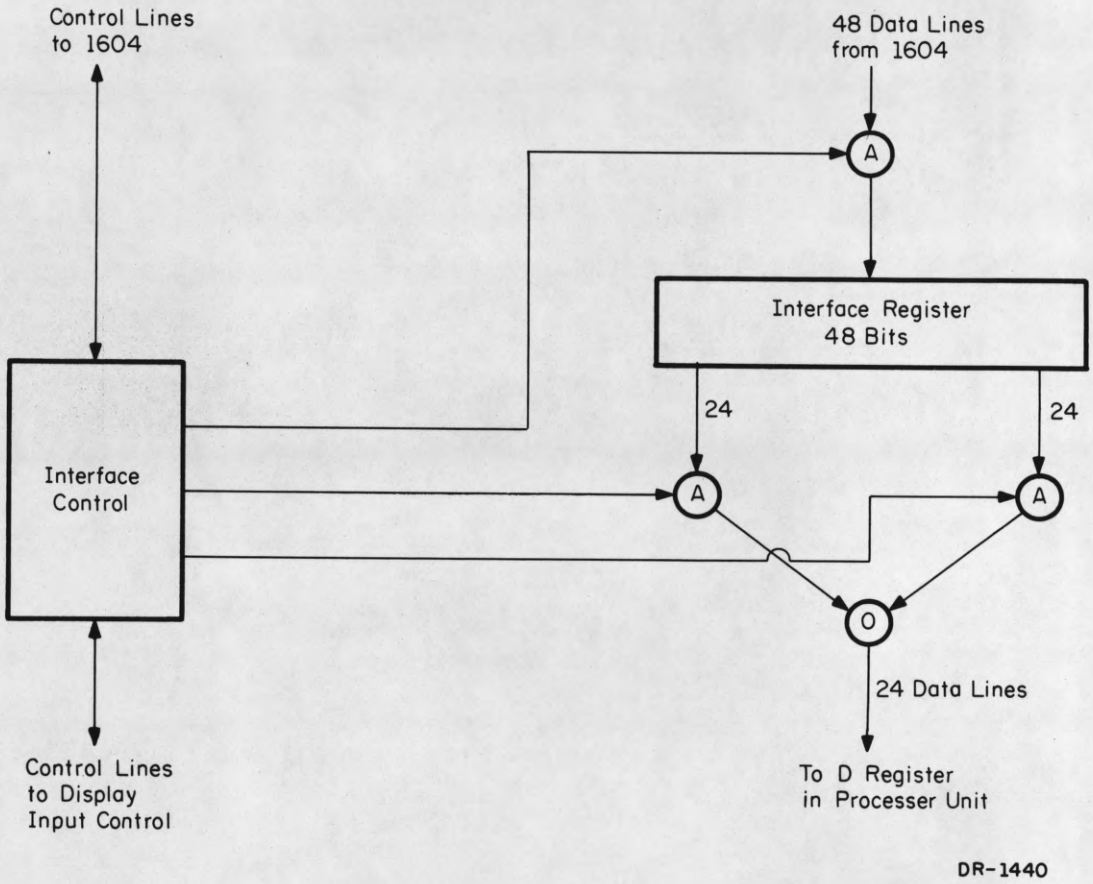


Fig. 3-1 INTERFACE UNIT

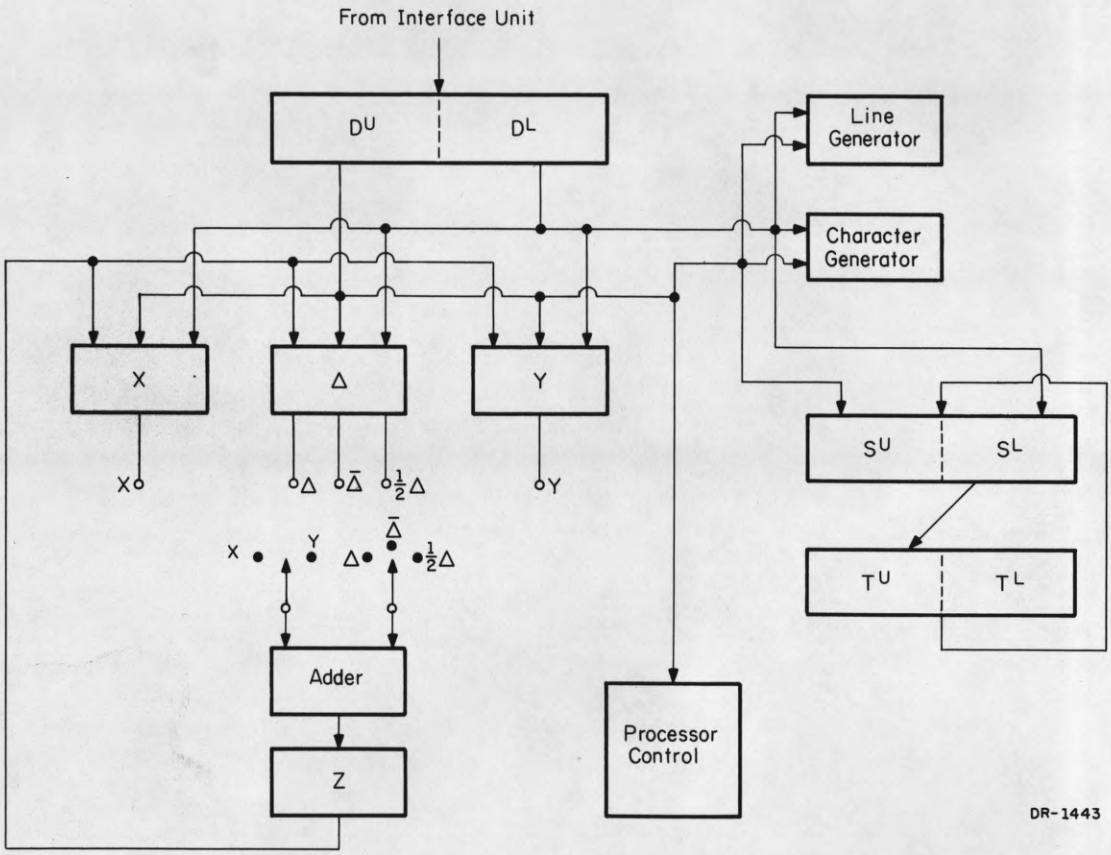


Fig. 3-2 PROCESSER UNIT

The Adder is a 12 bit two's complement adder. Adder input A_1 can be switched to either the X or Y register, while input A_2 can be switched to one of the three outputs of the Δ register.

The Z register is a 12 bit register connected to the output of the adder. This register is used as a temporary storage register during the processing of display data. The contents of this register may be transferred to the X, Y, or Δ register.

The ST register is a dual rank 24 bit shift register. The upper rank is designated S^U and S^L; and the lower rank T^U and T^L. This register is used in generating the symbol in a MODE 04 operation.

3-3 PROCESSER CONTROL

Processer control is divided into two sections, Input control and Mode control. See Fig. 3-3.

Input control directs the flow of data between the Interface unit and the Processer unit, while Mode control directs internal operations of the Processer unit.

Mode control is divided into control sequences. Each operating mode requires the use of only one sequence; however, more than one Mode may share a control sequence. Each control sequence supplies the Processer unit with the timing and control signals necessary to process the data in that mode.

Associated with Mode control is a 12 bit Mode register (M) which holds the upper 12 bits of the MCW. Bits 8-11 of M are decoded by Mode decode and used to select the proper control sequence. Bits 6-7 of M are sent to the Unblank circuit when they are used to set the intensity level.

Also contained in Mode control is a 5 bit binary counter (SC) which is used in Mode 04 and 07 operations.

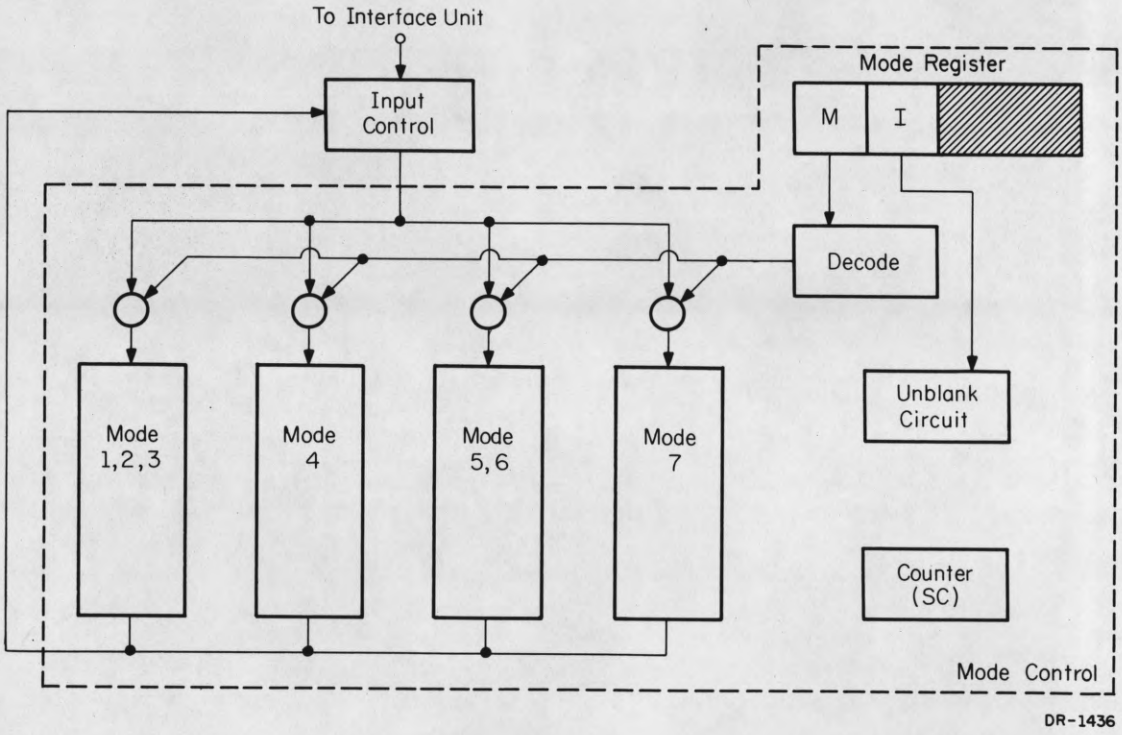


Fig. 3-3 PROCESSER CONTROL

3-4 ANALOG UNIT AND LINE GENERATOR

The Analog unit, Fig. 3-4, contains the circuits which determine the base position of the electron beam plus the circuits for generating lines in a Mode 05 or 06 operation.

Two 12 bit digital to analog (DA) converters convert the contents of the X and Y registers (in the Processer unit) into analog voltages. These voltages are sent to the X and Y summing amplifiers which drive the horizontal and vertical amplifiers in the CRT unit.

In line drawing operations, registers X and Y hold the origin coordinates of a line. Two 12 bit registers X_F and Y_F (in the Processer unit) hold the terminal coordinates. Attached to the X_F and Y_F registers are 12 bit DA converters identical to those of the X and Y registers. The output of X_F (Y_F) DA converter is subtracted from the output of the X (Y) DA at the input to the X_S (Y_S) sweep circuit. The X_S and Y_S sweep circuits, when triggered by Mode 05 or 06 control, generate sweep voltages proportional to X_F - X and Y_F - Y. These sweep voltages are then added to the origin point of the line at the input to the X and Y summing amplifiers.

The line intensity circuit generates a voltage proportional to the length of the line. This voltage is supplied to the Unblank circuit where it is used to maintain constant line intensity.

3-5 CHARACTER GENERATOR

The Character Generator uses a programmed dot technique to form each character within a 5 x 7 matrix shown in Fig. 3-5. The CRT beam is directed in sequence to only those positions within the matrix needed to form the character. The number of dots required to form a character ranges from 1 for a period to 20

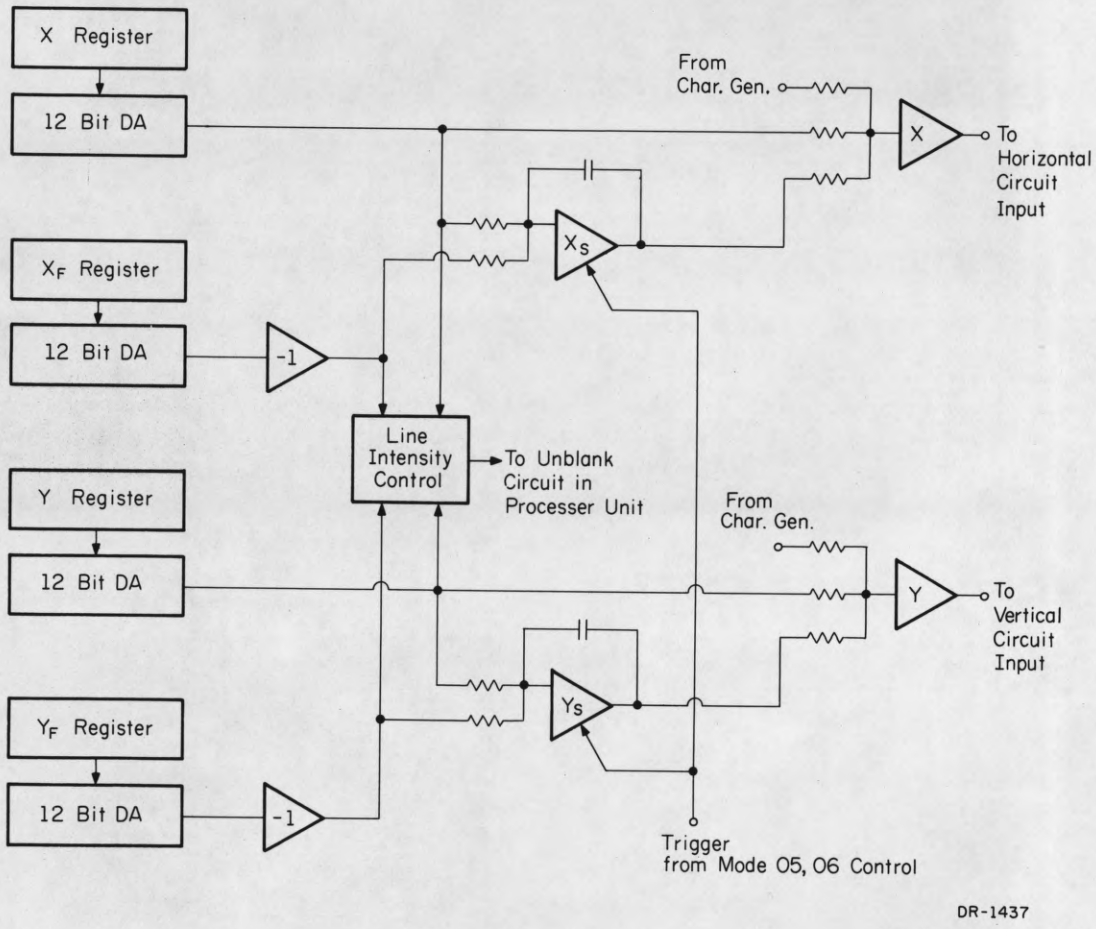


Fig. 3-4 ANALOG UNIT

for a B with an average of 15 dots required per character.

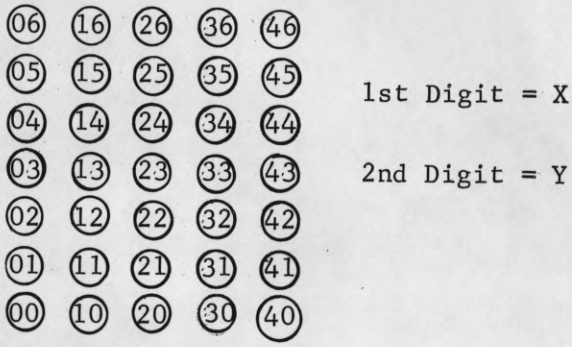


Fig. 3-5 Character Matrix

Operation of the Character Generator, Fig. 3-6 is supervised by Mode 07 control.

The Gating Logic transfers each of the four character codes, held by the D register, to the 6 bit Character register. The Shift Counter (SC) in Processer Control selects the code to be transferred. The first code (bits 06-11 of D^U) is transferred when SC = 0 and the last code (bits 00-05 of D^L) is transferred when SC = 3.

The Character Selection circuit decodes the contents of the character register into one of 64 select lines. The select lines for carriage return and space are sent to Mode 07 control while the other 62 select lines are used to select a set of diode switches in the Character Matrix.

The selected switches in the Character Matrix direct each point specified by the Point Counter (PC) to one of the 35 positions in the 5 x 7 matrix. Each of the 35 output lines from the Character Matrix is decoded by the Output Decode circuit into 3 bit X and Y values.

The 3 bit X_C and Y_C DA converters convert the X and Y digital values into analog voltages which are sent to the X and Y summing amplifiers

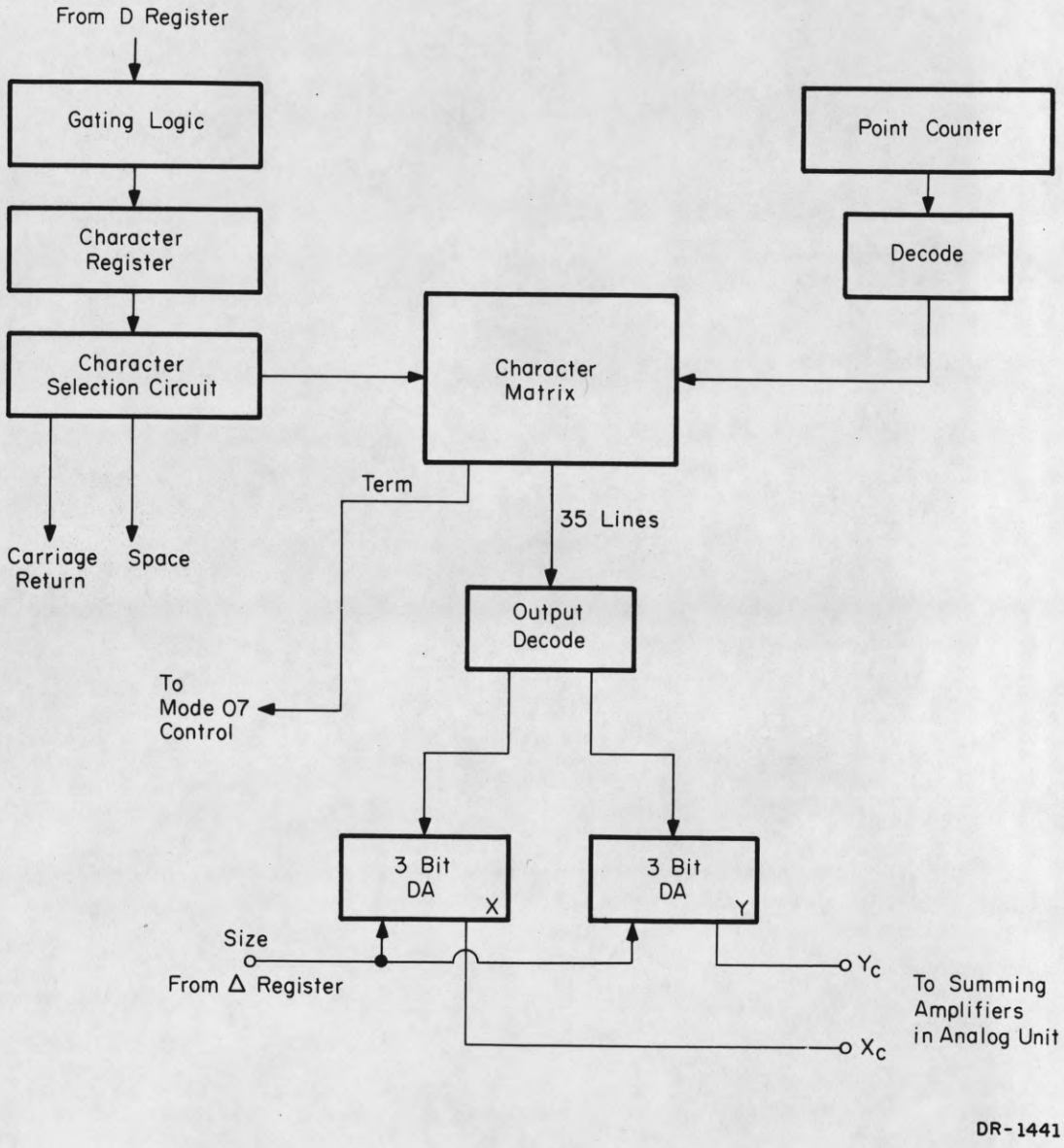


Fig. 3-6 CHARACTER GENERATOR

in the Analog unit. These voltages are added in the summing amplifier to the base position of the beam to form the character.

After the last point required to form the character has been displayed, the next point specified by the PC is directed by the Character Matrix to the TERM output. This signal will cause Mode 07 control to clear PC and SC, acquire a character code and move the base coordinates of the CRT beam into position for the next character.

3-6 CRT UNIT

The CRT unit is a Fairchild Type 737A Large Screen Indicator. This unit contains an electrostatically deflected 17 inch rectangular cathode ray tube and X and Y deflection amplifiers with a full output bandwidth of 1 megacycle.

3-7 CAMERA UNIT

The camera unit, Fig. 3-7, contains a magnetic deflected, electrostatic focused 5 inch CRT. Over a 2½ inch square on the face of the CRT, the maximum departure from linearity is 1.5% and the resolution is better than 1000 lines.

Mounted on the front of the camera unit is a Tektronix Model C 12 camera and a shutter control unit. The shutter may be operated manually or automatically from the computer program using display Mode 00.

3-8 TYPEWRITER

The typewriter provides the display operator with a means of communicating with the computer program. The typewriter may be used as a keyboard input or as an output device for producing printed copy.

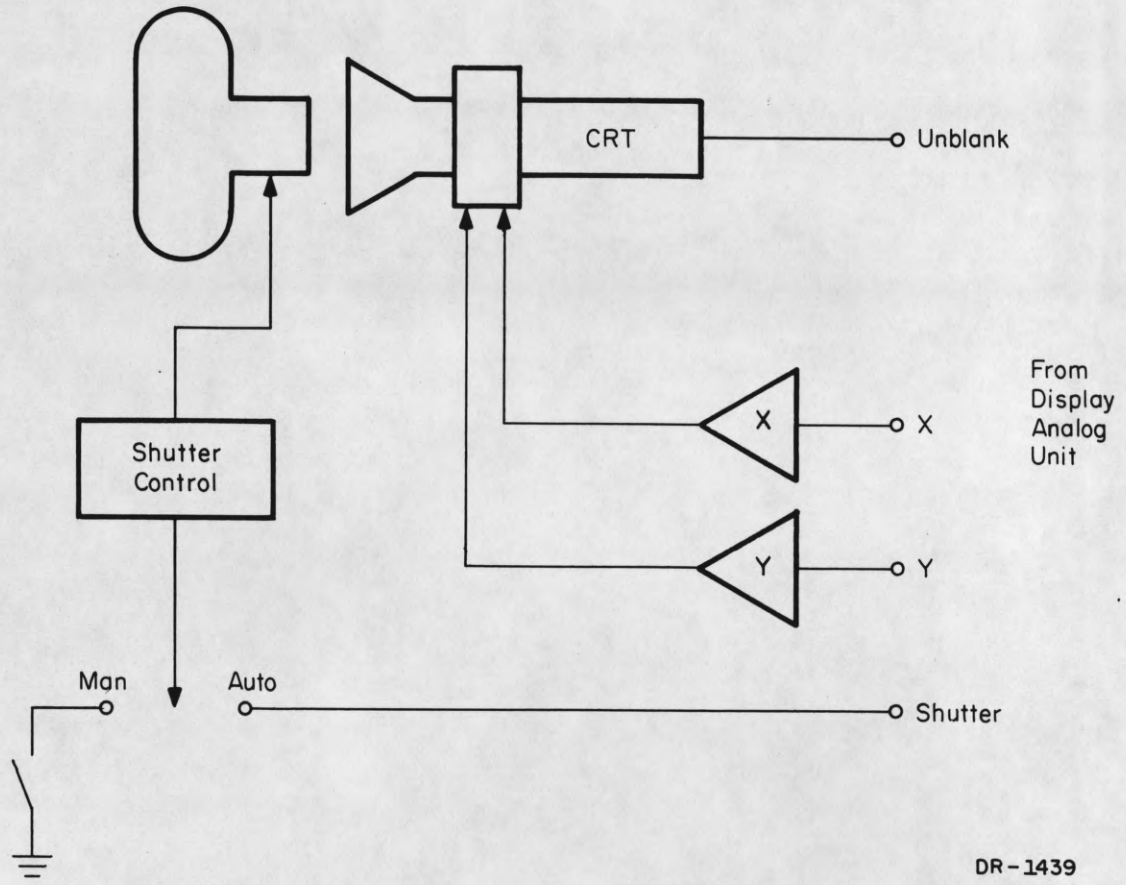


Fig. 3-7 CAMERA UNIT

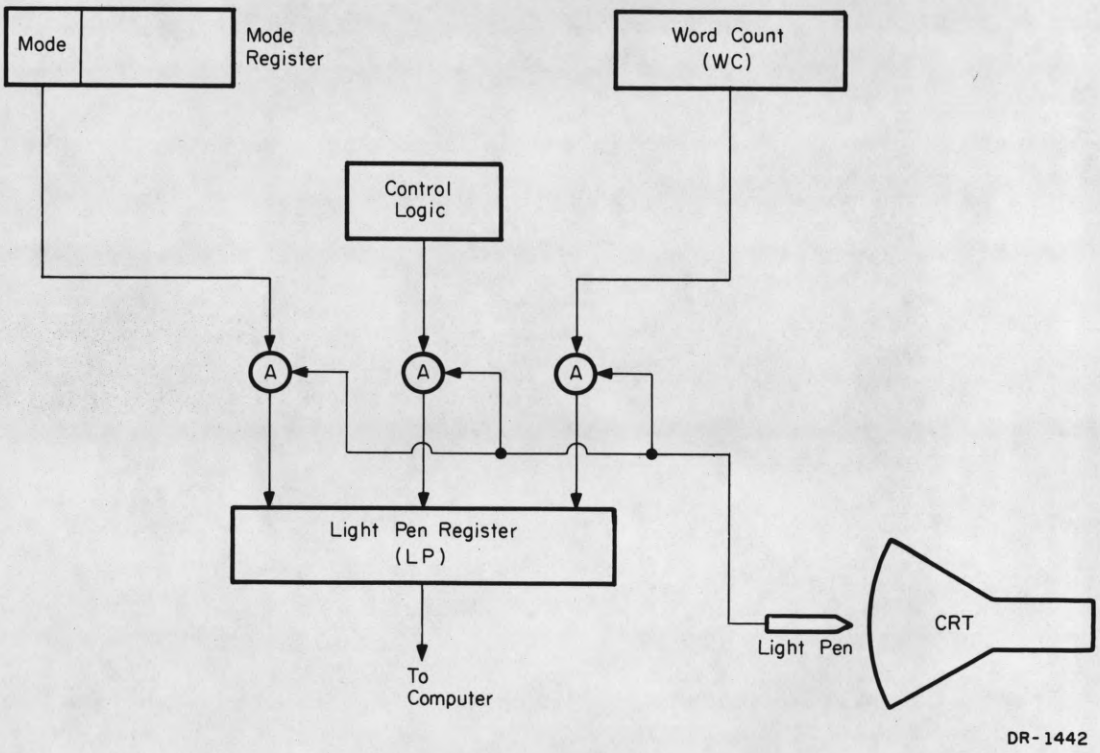


Fig. 3-8 LIGHT PEN

Before the typewriter can be used, the display operator must select it with the typewriter select switch on the display console. Selecting the display typewriter will disable the typewriter on the 1604 console. The display typewriter may then be used in exactly the same manner that the 1604 typewriter might be used. The Ext Clr switch on the computer console will disable the Display typewriter and return program control to the 1604 typewriter.

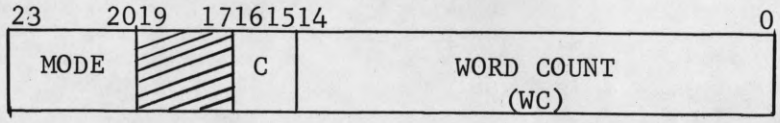
3-9 LIGHT PEN

The light pen provides a method of communicating with the computer program directly from the face of the CRT.

When the light pen, Fig. 3-8 detects light emanating from a point on the CRT, the contents of the Word Count register (WC), the mode bits from the Mode register, and two control (C) bits are assembled in the 24 bit Light Pen register (LP) and transferred to the computer.

The Word Count register is a 15 bit counter which is incremented each time a word enters the display Processer unit. This counter, which is cleared at the start of each computer output buffer, always contains the relative address of the computer word presently being processed by the display. The computer need only add this address to the buffer origin address to find the word described by the light pen.

The assembled light pen data word is shown in Fig. 3-9.



Bits 00-14 word count (WC)
Bits 15-16 control bits (C)
Bits 17-19 unused
Bits 20-23 mode

Fig. 3-9 LP Data Format

The 1604 computer interprets the word count as follows:

If bit 00 = 0, the display word will be found in the upper half of the memory location obtained by adding ½ WC to the buffer origin address. If bit 00 = 1, the display word will be found in the lower half of the memory location obtained by adding ½ WC to the buffer origin address.

Computer interpretation of the remaining LP data is as follows:

Mode 01 WC identifies location of XY coordinates of point

Mode 02 WC and C bits identify Y coordinate as follows:

C = 00 upper 12 bits at WC

C = 01 lower 12 bits at WC

Mode 03 WC and C bits identify X coordinate as follows:

C = 00 upper 12 bits at WC

C = 01 lower 12 bits at WC

Mode 04 Matrix origin is at WC-2

Mode 05, Mode 06 Line origin is at WC-1

This word count correction is made prior to adding WC to buffer origin address

Mode 07 WC and C bits identify character as follows:

C = 00 1st character at WC

C = 01 2nd character at WC

C = 10 3rd character at WC

C = 11 4th character at WC

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13. ABSTRACT

This report describes a cathode ray tube display unit designed for use as graphic output facility for a digital computer.

The display features a self contained character generator, line generator, photographic unit, and a light pen. Data may be displayed in up to seven different modes.

The maximum plotting rate is approximately 333,000 points/sec.

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Light Pen						
Digital Computer						
Character Generator						